

Profilometry Based on Heterodyne Interferometry with Nanometer Sensitivity

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Abstract:

Optical profilometry enables new dimensions of sensitivity in order to detect surface properties such as roughness and planeness of reflecting materials. For this purpose we developed an optical profilometer based on high-sensitivity heterodyne interferometry where a measurement beam is scanned over the surface of the device under test (DUT). With this measurement setup we are able to measure surfaces with approximately 5 nanometer accuracy. For scanning we developed a beam actuation system and a DUT actuation system with a lateral sensitivity of about 15 μ m.

Introduction:

In many areas of technology and science, the detection of the relevant parameters is only possible by using photons and optical technologies. Key benefits of photonic sensors are the achievable high resolutions and the non-tactile measuring principle. Compact and robust photonic sensor and actuator systems to detect surface properties such as roughness and waviness open new areas in manufacturing and quality assurance.

Conventional tactile 3D coordinate measuring machines with additional optical sensor systems and image processing methods are available with up to 10nm sensitivity (e.g. by Werth Messtechnik GmbH). Other optical profilometers are realized as microscopes mainly using scanning white light interferometry. They have a very limited dynamic range, the z-resolution of the sensor is in the range of 0.01nm to 0.1nm (e.g. by Veeco Instruments Inc. or Zygo). A white-light heterodyne interferometer with a resolution of 0.75nm was developed by Bosch GmbH [1,2].

In our setup we measure a change of optical path length between measurement and reference beam of a heterodyne interferometer. With this interferometer design, picometer sensitivity was demonstrated with a setup operated in vacuum [3]. While this interferometer setup only measures translation and tilt at one single spot, for surface property

measurements, a scan of the measurement beam over the surface under investigation is needed. The lateral resolution depends on the diameter of the measurement beam and therefore of the focal length of the lens in front of the device under test.

Optical Setup:

The laser beam with a wavelength of 1064nm is supplied by a Distributed Bragg Reflector (DBR) laser diode. To generate the heterodyne frequency, the laser beam is split into two separated beams, which are both shifted in frequency by two acousto-optic modulators (AOMs). The interferometer is built on a highly stable aluminum breadboard with a diameter of 23cm (cf. Figure 1). We designed a highly symmetric optical setup to achieve high common-mode rejection and therefore high accuracy and stability [3,4]. The lateral sensitivity is depending on the focal length of the lens in front of the sample. In our setup we are using a lens with a focal distance of 15mm corresponding to a lateral accuracy of about 15 μ m.

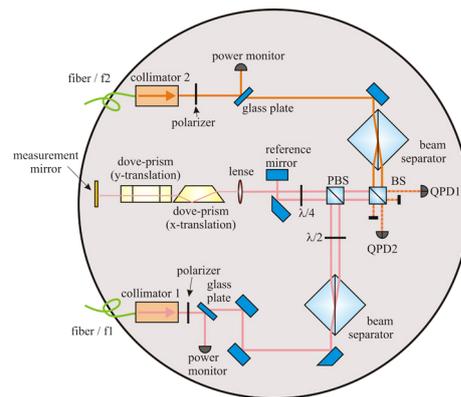
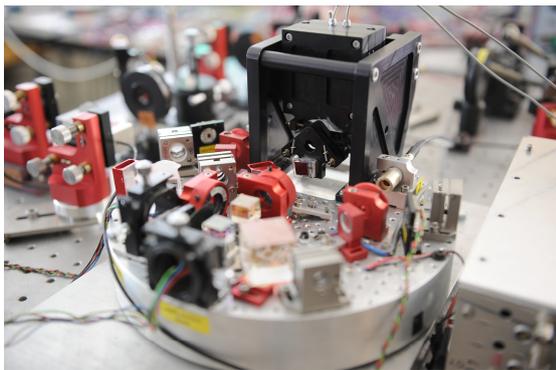


Fig. 1: Photograph (left) and schematic (right) of the current setup including interferometer board with optical components and the actuation system with the device under test. Shown is the schematic for measurement beam actuation.

Mechanical Setup for Actuation:

Our heterodyne interferometer measures the translation, i.e. a change in z direction, on a single point. To be able to measure a surface of a sample we designed two different scan methods for two dimensions: (i) DUT actuation und (ii) beam actuation.

In the first realization of a scanning method we actuated the DUT in front of the beam. Figure 1 shows the mechanical assembly and the mounted device under test. An xy-positioning stage is attached on a vertical plate that actuates the mount with the DUT. The positioning

stage PI-625 from the company Physics Instruments with a maximum traveling distance of 600 μ m in x and y direction and a resolution of 0.5nm was selected for this purpose. The sample is fixed on a mirror mount and can be adjusted perpendicularly to the beam.

A major advantage of the beam actuation design is the short optical path, the sample is attached directly after the last optical component of the interferometer. The optical setup is therefore particularly less susceptible to thermal fluctuations than the beam actuation system. Jerky actuation of the positioning table causes vibrations of the sample in z-direction and decreases the resolution in z-dimension. Furthermore, the positioning table is not set perfectly orthogonally to the beam and can not be adjusted with our current setup, thus creating a drift of the measured surface.

In the design of the actuation of the measurement beam, the beam is passing two Dove prisms mounted to a PZT translation stage (cf. Figure 2). By actuating the Dove prisms, theoretically no change of path length Δz is occurring by this setup. If the first prism for vertical actuation moves upwards, the beam is reflected in the prism in a way, that the outgoing beam is shifted to the same direction of the prism movement. The second prism is rotated by 90° and moves the beam parallel to the prism movement in the horizontal direction. A movement of the prisms in the direction in which they do not actuate the beam or in the direction of the optical axis does not have any influences to the position of the beam. The reflective surfaces of the prisms are manufactured with a precision of $\lambda/10$ and the angles with an accuracy of $\pm 36''$.

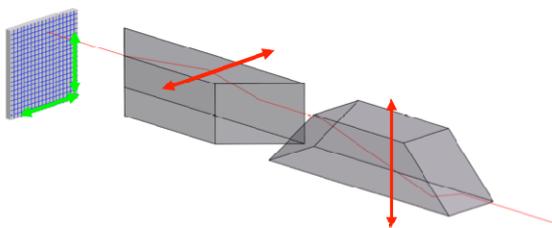


Fig. 2: Schematic of the beam actuation setup using two Dove prisms actuated as shown.

The mechanical setup for the beam actuation (cf. Figure 3) is significantly more complex than the DUT actuation. Nine degrees of freedom are needed to adjust the prisms and the positioning stage in order that the beam is orthogonal to the surface of the sample and the actuation axis perpendicular to the measurement beam. The temperature dependency is significantly higher than for the DUT actuation setup. This is caused by the asymmetry in the

measurement and reference arm using the additional optical components. The major advantage of the beam actuation setup is the positioning of the DUT, which is not part of the actuation system and makes the alignment of the sample easier.

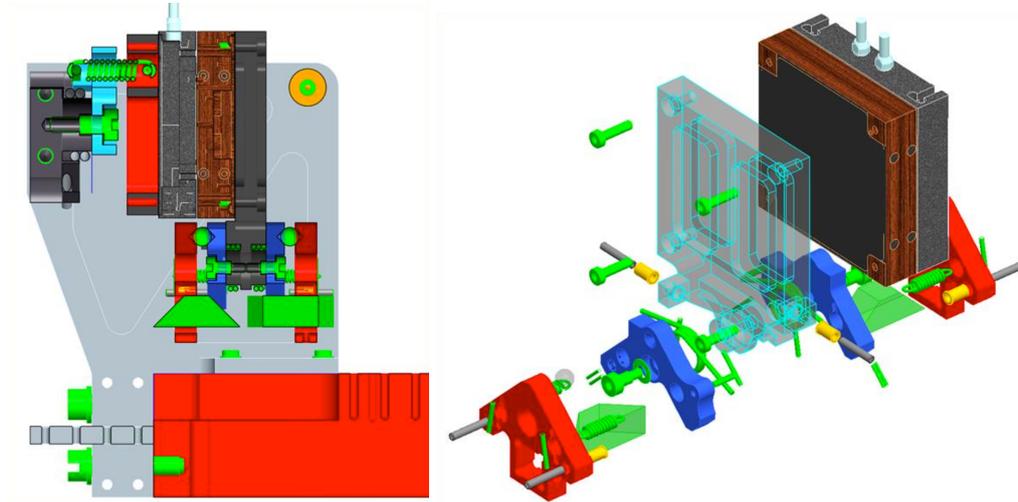


Fig. 3: CAD drawings of the beam actuation system.

Measurements:

We demonstrated the functionality of our profilometer by measuring a reference surface (set of gratings). A measurement of such a grating with a $200\mu\text{m}$ pitch and a depth of 90nm is shown in Figure 4. The sample with the gratings is rotated by 45° with respect to the directions of actuation and placed in a way that only a part of the sample with gratings is scanned. With this profile we can investigate systematic errors of our measurement system. For this measurement we scanned an area of $600\mu\text{m} \times 600\mu\text{m}$. In each measurement we have three drifts in the measured surface where the drifts in x and y directions are caused by misalignments of the sample. The sample is not perfectly aligned orthogonally to the beam. The third drift is a long term drift, which is mainly caused by temperature fluctuations during the measurement. For a measurement with 100×100 data points in x and y direction we need 1000s to scan a surface. The speed of the measurement can be increased, but the faster movements of the piezo cause vibrations and decrease the accuracy of our measurement.

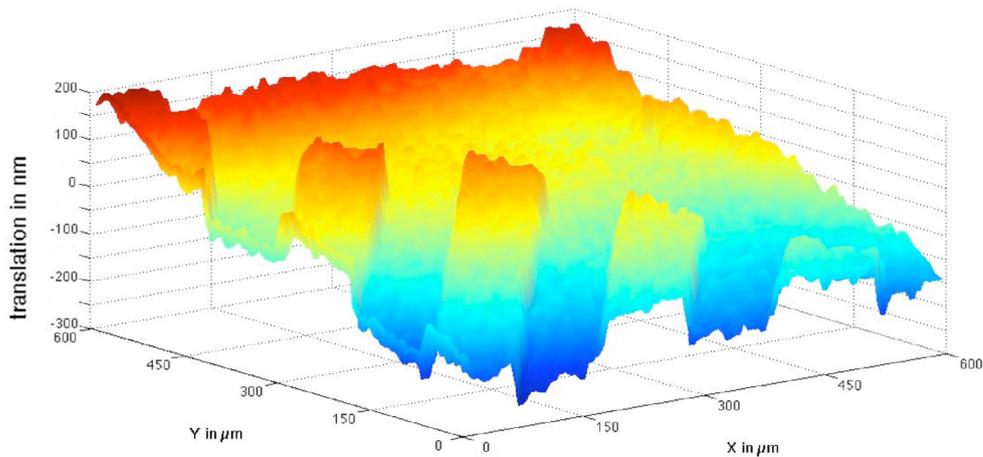


Fig. 4: Measurement of a reference surface with a 200μm pitch and 90nm depth.

Discussion and Outlook:

We presented our latest results with focus on our actuation systems with a lateral resolution of 15μm and a resolution in translation of ~5nm. With a new interferometer design we have a potential to increase the lateral resolution. A higher stability in the actuation system setup should increase the accuracy in translation down to about 10pm.

Acknowledgements:

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